BI-COMPONENT ELECTRICALLY CONDUCTIVE DRAWN
POLYESTER FIBER AND METHOD OF MAKING SAME

FIELD OF THE INVENTION

[01] The present invention is directed to conductive fibers and, more particularly, to bi-component electrically conductive drawn polyester fibers.

BACKGROUND OF THE INVENTION

[02] Friction generates static electricity in synthetic fibers, such as polyamide fibers, polyester fibers, acrylic fibers, etc., and also in some natural fibers such as wool. This is a disadvantage of synthetic fibers, especially when such fibers are used in applications where the discharge of static electricity (the characteristic shock) can have serious consequences. For example, the discharge of static electricity can damage computers and other electronic equipment. In some cases, such as in flammable atmospheres, the discharge of static electricity can result in a fire or explosion. Static buildup and discharge can also affect the efficiency and productivity of fiber conversion methods such as knitting and weaving.

[03] Because of the propensity of certain fibers to generate (or not dissipate) an electrical charge and because fibers are prevalent in many environments where static electricity is undesirable (e.g., carpet in computer rooms, clean room garments, uniforms, etc.), a large number of proposals to address the generation of static electricity have arisen. In general, these methods concern either imparting conductivity to the fibers themselves or to the article made from the fibers by incorporating one or more individually conductive fibers in

the article, or treating the fibers or article made from fibers with an antistatic surface treatment. Surface treatments are not generally desirable.

[04] U.S. Patents 5,698,148 and 5,776,608 to Asher et al. describe conductive fibers having a sheath/core configuration for incorporation into fibrous articles such as carpet or textiles. Electrically conductive carbon black is mixed in a synthetic thermoplastic fiber forming polyester to form a conductive sheath. A non-conductive core is made of the same synthetic thermoplastic fiber forming polyester used in the conductive sheath. The extruded fibers are drawn and then relaxed at a temperature above the polyester's glass transition temperature but below its melting or softening temperature.

[05] U.S. Patents 5,916,506 and 6,242,094 to Breznak et al. describe bi-component electrically conductive fibers in which a non-conductive first component is made of a first polymer, and a conductive second component is made of a second polymer containing a conductive material. The components are extruded into a sheath/core fiber, which is drawn to about four times its initial length to increase tensile strength. Such drawing causes a loss of conductivity, which can be restored by heat treatment. According to Breznak, a melting point difference between the two polymers of at least 20°C is preferred so that the heat treatment does not melt the core polymer. One drawback with this approach is that one of the polymers needs to be heated or cooled at the spinneret to account for their appreciable difference in melt temperature. This can undesirably lead to process breaks and release of monomer or oligomer at the spinneret.

[06]   Electrically conductive bi-component fibers generally exhibit a loss of conductivity upon drawing. This loss of conductivity traditionally has been counteracted by post-drawing treatments or by manipulating the drawing stage to minimize (but rarely reverse) this drop in conductivity. It would be desirable to develop a bi-component conductive fiber which does not exhibit a substantial loss of conductivity upon drawing. Such a fiber could be manufactured more efficiently by eliminating the need for post-drawing treatments or other measures aimed at increasing the conductivity of the drawn fiber.

SUMMARY OF THE INVENTION

[07]   According to one aspect of the present invention, a multi-component electrically conductive fiber has a first component comprising a first polyester having dispersed therein an electrically conductive material, and a second component comprising a second polyester which is not the same as the first polyester. The difference between the melting temperatures of the first and second polyesters is not more than about 10°C, and preferably the two melting temperatures are within about 2°C of each other. The first polyester typically is more amorphous than the second polyester before drying and/or crystallization steps performed prior to fiber spinning.

[08]   According to another aspect of the present invention, a method of preparing a drawn multi-component electrically conductive fiber is provided. The method comprises co-extruding a first component comprising a first polyester having dispersed therein an electrically conductive material and a second component

comprising a second polyester which is not the same as the first polyester. The fiber is thereafter drawn, while applying heat, to form a drawn fiber.

[09]   In preferred embodiments of the present invention, the drawn fiber, even without further treatment, has an electrical conductivity which is not substantially less than the electrical conductivity of undrawn fiber. In some cases, the electrical conductivity of the drawn fiber, surprisingly, is greater than that of the undrawn fiber. By avoiding the need for a separate post-drawing treatment for increasing conductivity, there exists the potential to increase manufacturing efficiency and cost effectiveness.

BRIEF DESCRIPTION OF THE DRAWINGS

[10]   The objects, features, and advantages of the invention will be apparent from the following more detailed description of certain embodiments of the invention and as illustrated in the accompanying drawings in which:

[11]   FIG. 1 is a cross-sectional view of a bi-component conductive fiber having a PBT center and a PET-based conductive component in accordance with a preferred embodiment of the invention; and

[12]   FIG. 2 is a schematic illustration of a typical spinning process for preparing a bi-component fiber in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[13]   The multi-component fiber of the present invention is prepared from a first polyester and a second polyester which is not the same as the first polyester. By "not the same" it is meant that the second polyester is prepared from a

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different combination of monomers than those used to prepare the first polyester. Commercially available polyesters can be used for each of the first and second polyesters, or suitable polyesters can be readily prepared by persons of ordinary skill. The term "multi-component" is used herein to refer synthetic fibers having more than one polymeric component and is particularly inclusive of bi-component fibers.

[14]   The multi-component fibers of the present invention are useful in a wide variety of applications such as textiles, industrial fabrics, and carpets. It is also contemplated that the multi-component fibers may be useful in other applications such as non-woven fabrics and, if further cut or processed, possibly in adhesives, interlayers, and the like. The fibers also are useful as staple fibers, e.g., where the fiber is spun, drawn, crimped, and cut into small discrete lengths, which can be blended with other staple fibers or carded and spun as a yarn by itself.

[15]   The first polyester generally functions as a carrier for the electrically conductive material in the first component of the multi-component fiber. The first polyester preferably is more amorphous than the second polyester, which improves compounding of the carbon and may also help to improve tenacity of the resulting fiber. The first polyester preferably is a polyethylene terephthalate (PET) based copolymer. The polyester may be modified, if necessary, so that its melting temperature is relatively close to (or possibly the same as) that of the second polyester. The difference in melting temperature between the first polyester and the second polyester is less than about 10°C,

preferably is less than about 5°C, and even more preferably is about 2°C or less.

[16]   In general, polyalkylene terephthalate or naphthalate polyesters can be prepared by the polycondensation reaction of terephthalic acid, or a lower alkyl ester thereof, and aliphatic or cycloaliphatic C2-C10 diols. For example, polyethylene terephthalate can be prepared by polycondensation of dimethyl terephthalate (DMT) and ethylene glycol followed by an ester interchange reaction.

[17]   There are several known methods to lower the degree of crystallinity and/or the melting temperature of a polyester. For example, many polyesters are prepared with a third monomer which is either a diol or a diacid (or is diacidic in reactivity). One example is PET modified with glycol, which is commercially available as PETG. Polycycloterephthalate (PCT) modified with glycol is commercially available as PCTG, while an acid-modified version of PCT is commercially available as PCTA. The acid-modifier is often a difunctional terephthalate such as dimethyl terephthalate or dimethyl isophthalate. Other difunctional acids, such as adipic acid, maleic acid, the different isomers of phthalic acid, and similar materials can be used. The diethyl ester versions of various diacids may be preferred to the diacid itself. Non-limiting examples of diol or glycol modifiers include ethylene-, diethylene-, and propylene glycols, butanediol, cyclohexanedimethanol, and other difunctional alcohols. The level of the co-monomer(s) in the polyester may vary over a wide range but typically is about 30 mol% or less, usually from about 1 to about 20 mol%, and often from about 5 to about 10 mol%.

[18]   One preferred PET based polyester is available pre-blended with conductive carbon black from Americhem, catalog no. 19420, which has a melting point of about 225°C.   Examples of other polyesters include a copolymer of terephthalic acid (TA) or dimethyl terephthalate (DMT), ethylene glycol (EOH), and cyclohexanedimethanol (CHDM), such as one of the Eastman PETG products.   Other non-limiting examples of polyesters include polytrimethylene terephthalate (PTT) based polymers and polybutylene terephthalate (PBT) based polymers.   Many other polyester-based carbon compounded materials are commercially available, such those available from Americhem under catalog nos. 16131 and 16222. RTP Company also has a line of carbon black filled polyester products which are marketed specifically for static control applications, under the name PermaStat®.   Such materials may be useful in making antistatic fibers with appropriate carbon loadings. In general, in order to obtain conductivity with carbon black-filled polymers, the amount of carbon black in the polymer is such that it cannot be used to form a fiber by itself.   The bi-component fibers described herein allow for heavily carbon-loaded polymers to be used in fibers by using a second polymer as the supporting substrate in the filament.

[19]   The second polyester generally is non-conductive and may be used to form the core, for example, in a sheath/core type fiber.   One preferred polyester for the second component is polybutylene terephthalate (PBT), which is derived from two main monomers, terephthalic acid (TA) (or dimethyl terephthalate (DMT)) and butanediol (BDO).   See "Handbook of Thermoplastic Polymers," Fakirov ed., 2002, Wiley-VCH.   PBT has a melting point of about 223°C. Other polyesters alternatively can be used in the second component, such as

polytrimethylene terephthalate (PTT), copolymers based on PTT or PET, copolymers such as PETG or PCT, or other polyesters useful in forming single-component fibers known to those skilled in the art.

[20]   The electrically conductive material may be conductive carbon black or other conductive material, such as conductive metals. Preferably, carbon black is dispersed in the first polyester. The loading of conductive material in the first component can vary over a wide range but most often ranges from about 10% to about 50% by weight, more usually from about 20% to about 30% by weight.

[21]   The multi-component fiber of the present invention preferably does not exhibit a substantial decrease in conductivity after drawing. Preferred fibers may exhibit a reduction in linear resistance after drawing by as much as 100 to 1,000 times. For example, when using PBT as the non-conductive polyester and Americhem 19420 as the carbon-filled polyester (25% carbon loading), it was found that the bi-component fibers consistently exhibited a decrease in linear resistance from 10^8-10^9 ohms/cm to 10^6-10^7 ohms/cm after drawing. This means that the conductivity, of efficacy in reducing static charge, improved by a factor of approximately 100 times.

[22]   The fibers typically are spun using about 11-13% of the conductive first component laid on the non-conductive second component as longitudinal stripes, as shown in FIG. 1. Alternatively, the first and second components of the multi-component fiber can be arranged as a sheath/core or any other suitable configuration presently known or hereafter developed for multi-component fibers. The particular arrangement of the first and second

components forms no part of the present invention. The bi-component fiber typically is spun at from about 1,000 to 2,000 meters per minute (mpm) and most often at about 1400 mpm. FIG. 2 is a schematic illustration of a typical fiber spinning process which can be used to prepare the bi-component fibers of the present invention.

[23]   The spun fiber can be drawn using any suitable equipment, such as a four roll Erdmann drawstand. The roll temperatures preferably are set above the glass transition temperatures of the polyesters. Typical drawing temperatures range from about 100 to about 190°C. In one preferred embodiment, the first and fourth rolls are set at 90°C and the remaining two "draw rolls" are set at 150°C. The fourth roll is normally called the relaxation roll, and is typically set at a temperature at or higher than the glass transition temperature (T_g) of one or both of the polymers. Retention and/or improvement in conductivity was observed over a wide range of relaxation temperatures, both above and below T_g.

[24]   One potential benefit from the relatively low differential in melt temperature between the first polyester and the second polyester is that the fiber can be manufactured using a common temperature at the spin pack. In other words, because of the similar melt temperatures, neither polyester is required to undergo an increase or decrease in temperature at the spinneret. This should translate into lower occurrences of process breaks and smoother processing due to less released monomer or oligomer at the spinneret.

[25]   The following examples are provided for illustrative purposes only and should not be regarded as limiting the invention.

Example 1

[26]   This example illustrates preparing a bi-component fiber in which polybutylene

terephthalate (PBT) was used for the non-conductive second component and a

PET-based polyester, Americhem 19420 (with 25% carbon loading), was used

for the conductive first component. Extrusion conditions are summarized in

the following table.

Machine Variable	Conductive PET-based Component	Non-conductive PBT
PROFILE TYPE	PBT	PBT
Extruder zone 1 (°C)	240	240
Extruder zone 2 (°C)	245	245
Extruder zone 3 (°C)	250	250
Flange (°C)	250	250
Transfer line (°C)	250	250
Meter Pump Outlet (°C)	260	260
Pack adapter (°C)	260	260
Pack well (°C)		258

[27]   A bi-component fiber was spun with 11-13% of the carbon-carrying polyester

laid on the PBT polymer as longitudinal stripes. The fiber was spun at 1400

mpm to give an approximately 45 denier fiber with tenacity of approximately

1.3 – 1.5 g/denier. The following table summarizes spinning conditions:

1st godet (mpm)	1400
2nd godet (mpm)	1420
Tension at windup	6-7 gms
Winder (mpm)	1425
Chimney air	150 cfm
Finish	12% oil in water
Target OOY	1.0-1.2 %
Target denier per position	45 +/- 2
Percent carbon component	11.5%
Stripes	3/fil

[28]   The linear resistance of the undrawn fiber was measured and was found to be

about 10^8-10^9 ohms/cm. Linear resistance was measured in this and other

examples herein using either a Keithley 614 electrometer or Keithley 6517 electrometer/high resistance meter. Fiber samples were 7.5 cm in length. Either 5 or 10 measurements were made and an average and standard deviation calculated. Fiber denier was measured using a reel of known circumference and the denier calculated as grams/9000 meters. Fiber tenacity was measured using an Instron 8100 tensile testing meter using Instron's Merlin software and was calculated as the breaking strength divided by denier.

[29]   The spun fiber was drawn on a four-roll Erdmann drawstand, of which the first and fourth rolls were set at 90°C and the other two "draw rolls" were set at 150°C. Drawing conditions are summarized in the following table.

Setting	Target Value	Units
D Roll Speed	1021.0	Mpm
A/Feed Ratio	1.050	
B/A Ratio	1.210	
C/B Ratio	1.520	
D/C Ratio	1.000	
Friction/D Ratio	0.970	
Total Draw Ratio	1.93	
Feed Roll Speed	528.7	Mpm
A Roll Speed	555.1	Mpm
B Roll Speed	671.7	Mpm
C Roll Speed	1021.0	Mpm
Friction Roll Speed	990.4	Mpm
A Temp	90	°C
B Temp	150	°C
C Temp	150	°C
D Temp	90	°C

[30]   The linear resistance of the drawn fiber was measured and was found to be about 10^6-10^7 ohms/cm. The tenacity of the fiber was measured and found to be about 2 g/denier.

Comparative Example 1

[31] This example illustrates preparing a bi-component fiber in which PBT was used for both the carbon-carrying component and the non-conductive second component. The carbon-carrying component was loaded with 25% of conductive carbon black. The fiber was spun and thereafter drawn essentially as described in Example 1. Tensile results and conductivity results are typical of several hundred items prepared using this combination of polymers, with varying amounts of carbon component, spinning speeds, and drawing temperatures.

Example 2

[32] This example illustrates preparing a bi-component fiber in which a PET-based polyester, Americhem 19420 (with 25% carbon loading), was used for the carbon-carrying component and the non-conductive second component was PTT. All other details are essentially as described above in Example 1.

Example 3

[33] This example illustrates preparing a bi-component fiber in which PBT filled with 25% carbon black was used for the carbon-carrying component and the non-conductive second component was PTT. All other details are essentially as described above in Example 1.

[34] Table 1 below summarizes the linear resistance and tenacity of the fibers of Example 1, Comparative Example 1, Example 2, and Example 3. The ratio of drawn to spun linear resistance indicates whether conductivity was unchanged

(ratio = 1.0), conductivity improved (ratio < 1.0), or conductivity decreased

(ratio > 1.0).

Table 1

Example	Denier as spun	Denier after drawing	Effective Draw (Spun/ Drawn Denier)	Spun Linear Resistance (ohm/cm)	Drawn Linear Resistance (ohm/cm)	Ratio: Drawn resistance /Spun resistance	Spun Tenacity (g/den)	Drawn Tenacity (g/den)
1	45	25	1.8	$5x\ 10^7$	8×10^6	0.16	1.2	2.00
Comp. 1	45	25	1.8	$3.5x\ 10^6$	$1.5x10^7$	4.3	0.87	1.48
2	45	25	1.8	$2.0x10^8$	$3.8x10^9$	19.0	1.11	1.40
3	45	25	1.8	$3.3x10^6$	$3.3x10^7$	10.0	0.99	1.10

[35]   The fiber of Example 1 exhibited about 35% more drawn tenacity than the

fiber of Comparative Example 1 prepared under the same processing

conditions, speeds, etc., with the same polymer processing temperatures. The

fiber of Example 1 thus provides improved tenacity over the fiber of

Comparative Example 1 while still permitting the two polymers of the bi-

component fiber to be processed at the same temperature because of their

similar melting temperatures. Further, the fiber of Example 1 had better

conductivity after drawing than did either the fiber of Comparative Example 1

or fibers, as in Examples 2-3, which were made with different combinations of

polyesters with other conditions being identical (in the cases where the melt

temperatures are the same) or changed to reflect the particular melt properties

of polymers with different melt temperatures.

Example 4

[36]   Table 2 below summarizes a number of other test items generated using

different grades of PBT as the non-conductive material, compared with

various conductive materials and two nylon-based conductive fibers. "19420"

refers to Americhem 19420 (with 25% carbon loading). These results show

the superior retention of properties with the appropriate choice of polymer

pairs versus other combinations of polymers. The examples in this table were

made using a fiber cross-section where the conductive material appears as

stripes along the longitudinal direction of the threadline. "% Stripe" is the

weight percent of the conductive polymer in the filament (where, in each case,

approximately 25% of the conductive polymer weight is carbon black). The

two columns showing "Avg Ohms/Cm" show the linear resistance in ohms/cm

of (1) Spun (or Sp) and (2) Drawn (or Dr) fibers. The last column shows the

ratio of drawn to spun linear resistance, where the ratio of drawn to spun linear

resistance indicates whether conductivity was unchanged (ratio = 1.0),

conductivity improved (ratio < 1.0), or conductivity decreased (ratio > 1.0).

Table 2

Core	Stripe	% Stripe	% Core	Avg of Sp Ohms / cm	Avg of Dr Ohms / cm	Avg of Dr / Sp Ohm
PBT - A	PBT – 1	10	90	2.58×10^6	1.37×10^7	5.46
PBT - A	PBT - 1	13	87	2.59×10^6	7.45×10^6	2.99
PBT - A	PBT - 1	16	84	2.12×10^6	6.48×10^6	3.34
PBT - B	PBT - 2	10	90	3.49×10^6	1.37×10^7	4.09
PBT - B	PBT - 2	13	87	2.12×10^6	4.99×10^6	2.35
PBT - B	PBT - 2	16	84	4.13×10^6	6.47×10^6	2.40
PBT - A	19420	13	87	5.33×10^7	1.12×10^7	0.21
PBT - A	19420	16	84	4.80×10^7	6.15×10^6	0.13
PBT - B	19420	10	90	9.60×10^7	1.52×10^7	0.16
PBT - B	19420	13	87	4.80×10^7	9.28×10^6	0.20
PBT - B	19420	16	84	4.00×10^7	7.40×10^6	0.19
PBT - C	PBT - 1	10	90	3.76×10^8	1.78×10^7	37.33
Nylon 66	Nylon 6	10	90	9.25×10^5	1.19×10^7	13.03
Nylon 66	Nylon 6	13	87	1.01×10^6	1.34×10^7	13.18
Nylon 66	Nylon 6	10	90	8.61×10^5	4.06×10^6	4.77
Nylon 66	Nylon 6	13	87	6.59×10^5	3.20×10^6	4.84
Nylon 66	Nylon 6	16	84	6.72×10^5	3.09×10^6	4.57

Examples 5-16

[37] The following examples show PBT/co-PET (Americhem 19420) polymer system for which the relative amount of drawing was moved between the roll pairs on the Erdmann four-roll draw-wind machine. The results are shown in the Table 3. As in the other examples, the ratio of drawn to spun linear resistance indicates whether conductivity was unchanged (ratio = 1.0), improved (ratio < 1.0), or decreased (ratio > 1.0).

Table 3

Example	5	6	7	8	9	10	11	12	13	14	15	16
Spun Steam P	12	12	12	12	6	6	6	6	0	0	0	0
D Roll Speed (Mpm)	1020.0	1080.0	1140.0	1180.0	1020.0	1080.0	1140.0	1180.0	1020.0	1080.0	1140.0	1180.0
A/Feed Ratio	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200	1.200
B/A Ratio	1.290	1.290	1.290	1.290	1.290	1.290	1.290	1.290	1.290	1.290	1.290	1.290
C/B Ratio	1.290	1.290	1.290	1.290	1.290	1.290	1.290	1.290	1.290	1.290	1.290	1.290
D/C Ratio	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Friction/D Ratio	0.955	0.955	0.955	0.955	0.955	0.955	0.955	0.955	0.955	0.955	0.955	0.955
Total Draw Ratio	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Feed Roll Speed (Mpm)	510.8	540.8	570.9	590.9	510.8	540.8	570.9	590.9	510.8	540.8	570.9	590.9
A Roll Speed (Mpm)	612.9	649.0	685.1	709.1	612.9	649.0	685.1	709.1	612.9	649.0	685.1	709.1
B Roll Speed (Mpm)	790.7	837.2	883.7	914.7	790.7	837.2	883.7	914.7	790.7	837.2	883.7	914.7
C Roll Speed (Mpm)	1020.0	1080.0	1140.0	1180.0	1020.0	1080.0	1140.0	1180.0	1020.0	1080.0	1140.0	1180.0
Friction Roll Speed (Mpm)	974.1	1031.4	1088.7	1126.9	974.1	1031.4	1088.7	1126.9	974.1	1031.4	1088.7	1126.9
Helix	6	6	6	6	6	6	6	6	6	6	6	6
Wobble	2	2	2	2	2	2	2	2	2	2	2	2
Period	6	6	6	6	6	6	6	6	6	6	6	6
A Temp (°C)	90	90	90	90	90	90	90	90	90	90	90	90
B Temp (°C)	150	150	150	150	150	150	150	150	150	150	150	150
C Temp (°C)	150	150	150	150	150	150	150	150	150	150	150	150
D Temp (°C)	90	90	90	90	90	90	90	90	90	90	90	90
Avg Tenacity (g/den)	2.36	2.29	2.37	2.23	2.33	2.27	2.29	2.55	2.00	2.12	2.05	2.09
Average of Ohms/cm	7.66E+07	5.22E+07	6.67E+07	5.87E+07	5.08E+07	5.07E+07	5.54E+07	9.26E+07	1.41E+08	3.47E+07	1.01E+08	3.20E+07
StdDev of Ohms/cm	5.77E+07	4.31E+07	2.11E+07	1.52E+07	3.41E+07	1.12E+07	2.09E+07	8.02E+07	1.58E+08	1.79E+07	1.02E+08	7.30E+06
Spun Ohms/7.5 cm	6.60E+08	7.80E+08	8.00E+08	8.20E+08	7.30E+08	7.10E+08	6.80E+08	7.10E+08	3.70E+08	4.70E+08	5.10E+08	4.20E+08
Spun Ohms/cm	8.80E+07	1.04E+08	1.07E+08	1.09E+08	9.73E+07	9.47E+07	9.07E+07	9.47E+07	4.93E+07	6.27E+07	6.80E+07	5.60E+07
Ratio resistance DR/SP	0.87	0.50	0.63	0.54	0.52	0.54	0.61	0.98	2.86	0.55	2.49	0.57

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Examples 17-40

[38]   The drawing method for the final product may include multiple draw zones as shown in the previous examples. However, the properties claimed herein can be obtained using a single-step drawing machine (e.g., a draw-wind process wherein the speed differential between two rolls provides the drawing from the starting spun denier to the final product denier). In this method, the so-called "relaxation zone" provided by multiple-roll draw-wind machines is not present.

[39]   Table 5 summarizes property results of items generated in a factorial run. In this example, the spun fiber was made using the PBT/co-PET polymer system as discussed earlier. Take-up speed for both spun items was 1420 mpm. As in the other examples, the ratio of drawn to spun linear resistance indicates whether conductivity was unchanged (ratio = 1.0), improved (ratio < 1.0), or decreased (ratio > 1.0). Test items made using spun item 117 had 9.5% by weight of the conductive carbon polymer in each threadline; items made using spun item 122 had 14.5%. The first draw roll temperature was set at 100°C for all runs shown below. "Draw ratio" shown is the speed ratio between the two rolls where the 2nd roll was set at 1020 mpm for all items. Machine settings are shown in Table 6.

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Table 5

Example	Draw ratio	2nd roll T (°C)	Spun	Average of Ohms/cm	Ratio Drawn R/ Spun R	Average of Denier	Average of Brk Str	Average of Elong %	Average of Ten g/d
17	2.1	140	117	1.01E+08	0.76	23.13	65.67	38.16	2.84
18	1.8	140	117	6.67E+07	0.50	27.07	60.07	58.88	2.22
19	1.95	140	117	8.80E+07	0.66	25.02	61.82	47.57	2.47
20	1.8	·120	117	1.39E+08	1.04	27.20	61.34	60.44	2.26
21	1.95	160	117	9.07E+07	0.68	25.05	64.08	43.31	2.56
22	2.1	160	117	7.47E+07	0.56	23.20	66.70	33.85	2.88
23	1.95	140	117	1.09E+08	0.82	24.90	61.23	44.23	2.46
24	1.8	160	117	6.13E+07	0.46	27.00	62.72	57.30	2.32
25	2.1	120	117	2.91E+08	2.17	23.20	62.34	37.20	2.69
26	1.95	140	117	8.80E+07	0.66	25.05	60.98	44.89	2.44
27	1.95	120	117	1.63E+08	1.22	25.00	62.29	49.61	2.49
28	1.95	140	117	7.80E+07	0.58	24.90	61.58	42.11	2.47
29	2.1	140	122	5.07E+07	0.78	23.18	55.84	34.67	2.41
30	1.8	140	122	3.20E+07	0.49	27.13	51.88	56.59	1.91
31	1.95	140	122	4.00E+07	0.61	24.87	51.92	40.40	2.09
32	1.8	120	122	5.87E+07	0.90	27.14	51.09	59.28	1.88
33	1.95	160	122	2.40E+07	0.37	25.06	55.71	44.81	2.22
34	2.1	160	122	2.67E+07	0.41	23.13	57.91	32.83	2.50
35	1.95	140	122	3.73E+07	0.57	24.96	52.69	42.80	2.11
36	1.8	160	122	1.87E+07	0.29	27.00	54.25	56.27	2.01
37	2.1	120	122	8.80E+07	1.35	23.31	53.89	36.41	2.31
38	1.95	140	122	5.07E+07	0.78	25.12	52.55	43.05	2.09
39	1.95	120	122	7.73E+07	1.18	25.14	52.30	47.59	2.08
40	1.95	140	122	3.93E+07	0.60	24.88	53.06	42.53	2.13

Table 6

Spun Item 117					
Example	D Rat	T2 (°C)	A/Feed	D roll	Feed roll
17	2.1	140	1.05	1020	485.71
18	1.8	140	1.05	1020	566.67·
19	1.95	140	1.05	1020	523.08
20	1.8	120	1.05	1020	566.67
21	1.95	160	1.05	1020	523.08
22	2.1	160	1.05	1020	485.71
23	1.95	140	1.05	1020	523.08
24	1.8	160	1.05	1020	566.67
25	2.1	120	1.05	1020	485.71
26	1.95	140	1.05	1020	523.08
27	1.95	120	1.05	1020	523.08
28	1.95	140	1.05	1020	523.08
Spun Item 122					
Example	D Rat	T2 (°C)	A/Feed	D roll	Feed roll
29	2.1	140	1.05	1020	485.71
30	1.8	140	1.05	1020	566.67
31	1.95	140	1.05	1020	523.08
32	1.8	120	1.05	1020	566.67
33	1.95	160	1.05	1020	523.08
34	2.1	160	1.05	1020	485.71
35	1.95	140	1.05	1020	523.08
36	1.8	160	1.05	1020	566.67
37	2.1	120	1.05	1020	485.71
38	1.95	140	1.05	1020	523.08
39	1.95	120	1.05	1020	523.08
40	1.95	140	1.05	1020	523.08

Examples 41-44

[40]   Fibers made using this method may also be useful in staple fiber applications, *e.g.*, where the bi-component fiber as described here is spun, drawn, crimped, and cut into small discrete lengths to be blended with other staple fibers, or to be carded and spun as a yarn by itself. As an example, a fiber using a single-stripe of conductive carbon filled co-PET and a non-conductive "core" polymer of PBT was spun at the conditions shown below. This fiber was then made into a tow by combining multiple ends of the spun yarn into a single large bundle, and said tow was drawn, crimped, and cut into staple. The staple was found to have a resistance adequate for antistatic fabric uses. Further, by selecting the appropriate combinations of draw roll temperature and draw ratio, the final staple product can be formed such that its measured surface resistance is lower than that of the spun fiber (*i.e.*, draw resistance / spun resistance < 0). Table 7 summarizes resistance results for several staple items made using the same spun yarn feedstock.

Table 7

Example	41	42	43	44
Spun Tow Denier	19836	19836	19836	19836
Drawn Tow Denier	13671	15228	13842	15201
DPF	2.85	3.17	2.88	3.17
Spun Tow Linear Resistance (ohms/cm)	2.00E+09	2.00E+09	2.00E+09	2.00E+09
	1.05E+09	1.05E+09	1.05E+09	1.05E+09
	1.92E+09	1.92E+09	1.92E+09	1.92E+09
Average	1.66E+09	1.66E+09	1.66E+09	1.66E+09
Drawn Tow Linear Resistance (ohms/cm)	1.30E+14	3.20E+14	2.70E+08	3.30E+08
	2.20E+13	3.80E+14	2.80E+08	2.00E+08
	4.20E+14	2.70E+14	2.10E+08	1.70E+08
Average	1.91E+14	3.23E+14	2.53E+08	2.33E+08
Spun Tow Surface Resistance (ohms)	2.40E+07	2.40E+07	2.40E+07	2.40E+07
	2.80E+07	2.80E+07	2.80E+07	2.80E+07
	2.40E+07	2.40E+07	2.40E+07	2.40E+07
Average	2.53E+07	2.53E+07	2.53E+07	2.53E+07
Drawn Tow Surface Resistance (ohms)	3.00E+06	7.00E+05	1.60E+05	2.00E+05
	2.60E+06	6.00E+05	1.80E+05	1.80E+05
	9.00E+06	9.00E+05	1.60E+05	1.60E+05
Average	4.87E+06	7.33E+05	1.67E+05	1.80E+05
Staple Surface Resistance (ohms)	3.00E+09	1.60E+07	3.20E+05	1.80E+05
	6.00E+07	1.80E+07	2.80E+05	2.20E+05
	6.50E+07	2.00E+07	2.60E+05	2.00E+05
Average	1.04E+09	1.80E+07	2.87E+05	2.00E+05
Draw Ratio	1.6	1.43	1.6	1.43
Heat on Rolls	NO	NO	113 °C	113 °C
Resistance ratios				
Drawn tow/Spun tow Linear Resistance (ohms/cm)	1.15E+05	1.95E+05	1.53E-01	1.41E-01
Drawn tow/Spun tow Surface Resistance (ohms)	1.92E-01	2.89E-02	6.58E-03	7.11E-03
Staple/Spun tow Surface Resistance (ohms)	4.11E+01	7.11E-01	1.13E-02	7.89E-03

[41]　As in the other examples, the ratio of drawn to spun resistance indicates whether conductivity was unchanged (ratio = 1.0), improved (ratio < 1.0), or decreased (ratio > 1.0). Linear resistance was measured as described earlier (in units of ohms/cm). Surface resistance is more appropriate for measuring swatches or collections of small fibers, fibrils, or flat surfaces (results above are shown in ohms). It is measured by taking a sample of fiber or fabric and conditioning it for the appropriate amount of time in a controlled temperature and humidity environment. An appropriate amount of sample is prepared for presentation to the electrode. An external voltage source is set to 100V and the resistivity of the sample at the applied voltage is measured once the reading is allowed to stabilize for several seconds.

[42]   The test probe used here is the EOS/EDS standard 11.11 surface resistivity probe Model 803B from Electro-Tech Systems (Glenside, PA), which consists of two concentric soft rubber electrodes. The dimensions of the electrodes are such that the surface resistance in ohms/square is 10 times the measured resistance (in ohms). Readings were made using the Model 872A Wide Range Resistance Meter from Electro-Tech, or the Keithley 6517 Resistance Meter.

[43]   It will be understood that while the invention has been described in conjunction with specific embodiments thereof, the foregoing description and examples are intended to illustrate, but not limit the scope of the invention. Other aspects, advantages and modifications will be apparent to those skilled in the art to which the invention pertains, and these aspects and modifications are within the scope of the invention, which is limited only by the appended claims.